AN OUTLINE OF RADIATIVELY-DRIVEN COSMOLOGY

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ABSTRACT

A Big Bang universe consisting, before recombination, of H, D, ^{3}He, ^{4}He, ^{6}Li, and ^{7}Li ions, electrons, photons, and massless neutrinos, at closure density, with a galaxy-size perturbation spectrum but no large-scale structure, will evolve into the universe as we now observe it. Evolution during the first billion years is controlled by radiation. Globular clusters are formed by radiatively-driven implosions, galaxies are formed by radiatively triggered gravitational collapse of systems of globular clusters, and voids are formed by radiatively-driven expansion. After this period the strong radiation sources are exhausted and the universe has expanded to the point where further evolution is determined by gravity and universal expansion.
Subject headings: cosmology — stars: Population III — stars: Population II — clusters: globular — galaxies: evolution

1. INTRODUCTION

Cosmology suffers from the same sort of conceptual error as did geology and evolutionary biology earlier in this century. "Gradualism" or "uniformitarianism" and slow changes are assumed, probably because it makes modeling easier. "There was the Big Bang. There was decoupling (= recombination). Nothing much else has happened. Gravity is the only force that matters. Evolution is proceeding slowly and only a fraction of matter has formed galaxies and stars. The "microwave" background just sits there. The only important science is determining the expansion parameters". Gradual evolution has always turned out to be a delusion produced by oversimplification.

In reality, a second force is produced by radiative acceleration. It triggers rapid collapses that go to almost 100% completion. It produces "catastrophic" or "episodic" evolution.

Here we present the results of gedanken experiments (Kurucz 1992) in a traditional, linear, chronological sequence in the hope of stimulating research on the many topics considered.

2. CONDITIONS BEFORE RECOMBINATION

The evolution of the universe from before recombination to the present time can be explained by simple, elementary physics. Let us start when the universe is a few hundred thousand years old, at the time when the temperature has fallen to about 10000K. Let it consist of H, D, ^{3}He, ^{4}He, ^{6}Li, and ^{7}Li ions, electrons, photons, and massless neutrinos at the closure density, between 10^4 and 10^5 per cubic centimeter. Abundances are taken from standard Big Bang nucleosynthesis calculations shown in Figure 1. These abundances are ten times higher for Li, 10 times lower for ^{3}He and D than cosmologists have assumed in the past but they are consistant with observation (Kurucz 1995) in that there are no observations of primordial ^{3}He or D, and in that the Li abundance in extreme Population II stars has been grossly underestimated.

The gas is opaque. The redshift Z is approximately 1300. There is uniform expansion and cooling of the universe. There is no large-scale structure; the universe is filled with galaxy-size perturbations in density and temperature that were created at an earlier time. As the universe expands those perturbations evolve into highly structured galaxies with myriad condensations, and the galaxies themselves form large-scale structures.

3. GALAXY-SIZE PERTURBATIONS

Ignoring mergers and collisional destruction, every galaxy extant corresponds to a prerecombination perturbation, and vice versa. Thus the distribution function for the perturbation masses is approximately the distribution function for galaxy masses now, except at the extremes. There are no symmetries in the initial galaxy-size perturbations. They have facets, convexities, concavities, etc. from early close packing (as in a Voronoi tesselation). Because there is no symmetry, every perturbation has angular momentum.

The perturbations are in quasi-hydrostatic equilibrium with gravity pulling inward trying to increase the density while radiative acceleration pushes outward trying to smooth out the perturbation. The cosmological expansion enhances the perturbation. The denser, hotter regions are compressed (i.e., they expand less rapidly) while less dense regions are pulled apart. The local gravity vector g does not point radially toward the perturbation "center". The radiative acceleration vector g_{rad} has similar components pointing in the opposite direction. The effective gravity at any point is $g_{eff} = g + g_{rad}$. The surface and volume of the perturbations are defined by the surfaces $g_{eff} = 0$.

From this starting point the universe continues to expand and cool until the temperature drops to a few thousand degrees. The electrons combine with the ions until most of the matter is neutral or negative. The opacity of the gas drops and radiative acceleration plummets.

Recombination actually starts as soon as electrons and protons are formed. What happens at "recombination" or "decoupling" is that photoionization (of hydrogen) stops. The electron number density drops drastically so that the gas pressure drops by a factor of 2. The electron contribution to the opacity drops drastically as does the radiative acceleration.

Recombination and cooling is much more complicated than has been assumed. The recombinations in order of energy are

$^{7}Li^{+++} + e > {}^{7}Li^{++} + 987660$ cm-1
$^{6}Li^{+++} + e > {}^{6}Li^{++} + 987647$ cm-1
$^{7}Li^{++} + e > {}^{7}Li^{+} + 610080$
$^{6}Li^{++} + e > {}^{6}Li^{+} + 610066$
$^{4}He^{++} + e > {}^{4}He^{+} + 438909$
$^{3}He^{++} + e > {}^{3}He^{+} + 438889$
$^{4}He^{+} + e > {}^{4}He + 198311$
$^{3}He^{+} + e > {}^{3}He + 198291$?
$^{2}H^{+} + e > {}^{2}H + 109709$
$^{1}H^{+} + e > {}^{1}H + 109679$
$^{7}Li^{+} + e > {}^{7}Li + 43487$
$^{6}Li^{+} + e > {}^{6}Li + 43472$
$^{2}H + e > {}^{2}H^{-} + 6061+$?
$^{1}H + e > {}^{1}H^{-} + 6061$
$^{7}Li + e > {}^{7}Li^{-} + 4981$
$^{6}Li + e > {}^{6}Li^{-} + 4981-$?

At the same time, there may also be high temperature molecules: all the positive and negative ions of Li_2, LiHe, LiH, He_2, HeH, and H_2 and their isotopomers. For example,

$^{7}Li^{1}H^{++}$ $^{7}Li^{1}H^{+}$ $^{7}Li^{1}H$ $^{7}Li^{1}H^{-}$
$^{7}Li^{2}H^{++}$ $^{7}Li^{2}H^{+}$ $^{7}Li^{2}H$ $^{7}Li^{2}H^{-}$
$^{6}Li^{1}H^{++}$ $^{6}Li^{1}H^{+}$ $^{6}Li^{1}H$ $^{6}Li^{1}H^{-}$
$^{6}Li^{2}H^{++}$ $^{6}Li^{2}H^{+}$ $^{6}Li^{2}H$ $^{6}Li^{2}H^{-}$

Passing through each He recombination reduces the number of particles and the gas pressure by 5%. The H recombination reduces the number of particles and the gas pressure by 45%. Li remains partially ionized and provides free electrons which can form H^- and Li^-. It can also participate in charge exchange reactions.

Decoupling is never complete because there are free electrons from the Li that Thomson scatter, because H and He Rayleigh scatter, because Li has lines in the visible that are optically thick on globular cluster scales, and because H^- has continuous absorption in the visible and infrared that is optically thick at galaxy scales. The universe is optically thick to the recombination radiation. Thus the "microwave" background is not from the primordial black body but from a later time.

5. FORMATION OF GLOBULAR-CLUSTER-SIZE PERTURBATIONS

When the radiation field suddenly decouples, g_{rad} becomes small and P_{gas} collapses by a factor of more than 2, and g_{eff} suddenly, impulsively increases to g. This inward impulse produces waves that travel at the speed of sound. However, because there is no symmetry, these waves cannot behave coherently. They cannot propagate far before interacting with other waves. They interfere in three dimensions. Perhaps they form shocks. The globular-cluster-size perturbation spectrum that they produce has high-density, low-mass maxima and low-density minima, all superimposed on the galaxy-size perturbation (Figure 2). At this stage every point in the universe has two peculiar velocity components: one toward the local globular-cluster-size perturbation maximum and one toward the local galaxy-size perturbation maximum. Research is needed to find out whether the waves leave behind microturbulent motions in the perturbations.

The temperature changes in the new perturbations are spectacular. In the less dense regions the temperature drops. In the dense centers the gas heats and partially ionizes. The opacity increases. Positively and negatively charged atoms and molecules flourish and radiate through the cool surface. As soon as the "recombination" or "decoupling" era begins it is over. The background blackbody radiation is completely destroyed. The radiation field comes from globular-cluster-size perturbations irradiating each other.

The universal expansion amplifies perturbations. Minima become relatively wider and maxima become sharper, both on the galaxy-size scale and on the globular-cluster-size scale. The universal expansion naturally separates the galaxy-size-perturbations and produces surfaces through which there can be outward flux. This also happens with the globular-cluster-size perturbations, and the outermost globular-cluster-size perturbations can radiate out of the galaxy-size perturbations and thus cool more rapidly than interior perturbations.

Coldness is a modern invention. The temperature of any matter never got below 500K, say, until the initial Population II stars produced dust by mass loss. The physics of the contemporary interstellar medium is not relevant at early times.

6. FORMATION OF POPULATION III STARS

The universe expands by a factor of 100 from recombination, say z = 1300, to Population III star formation, say z = 13 . The background radiation produced by the collapsing perturbations cools proportionally and fills the expanded volume. This radiation is always coupled to the perturbations. Even when it is redshifted by a factor of 100, it is still absorbed by molecules in the perturbations.

Li and any heteronuclear molecules have lines in the visible and infrared. There are between 300,000 and 400,000 lines: electronic, vibrational-rotational, and rotational. The red-shifted background radiation produces an overpopulation of the excited levels. The excited levels can absorb radiation and then emit at higher frequencies that are not likely to be absorbed by the cooler surface. This mechanism allows the perturbation to get rid of excess energy from the collapse. There are likely to be fluoresences that couple the different species and produce energy redistributions. The line opacity may be enhanced by the high microturbulent velocity. Differential velocities from the collapse can reduce or enhance absorption and emission.

The perturbations range in mass from more than 100 $M_\odot$ to $10^6 M_\odot$. The perturbations can collapse only as fast as excess energy can escape in radiation. A small perturbation radiatively cools faster than a large perturbation because it has a larger surface to volume ratio. The outermost perturbations radiate mostly into open space between the galaxy-size perturbations. The smallest perturbations collapse to form, say, 100 $M_\odot$ Population III stars.

7. FORMATION OF GLOBULAR CLUSTERS

Massive Population III stars are superluminous. They radiate about 10^{53} ergs in 10^6 years and then explode as supernovas. These are the only Population III stars and only their dead supernova remnants now remain, amounting to only a small fraction of the mass of the universe. Because there is not enough time for larger perturbations to evolve, all other matter in the universe is contaminated by the supernovas and becomes Population II material.

No matter what the perturbation spectrum, the big perturbations will in general be surrounded by small perturbations. These might have masses as small as 100 $M_\odot$. In diameter, these are only 20 times smaller than a 10^6 $M_\odot$ perturbation and 50 times smaller than a 10^7 $M_\odot$ perturbation. The radiative acceleration from each Population III star contributes to the radiatively-driven implosion of all its neighboring perturbations into globular clusters. Four Population III stars tetrahedrally arranged may be sufficient to implode the largest perturbations.

Globular cluster formation happens in layers like an onion. The surface of a perturbation is compressed and contaminated by the Population III stars. It becomes optically thick and forms a layer of Population II stars and becomes optically thin again. Simple versions of this process for radiatively imploding bumps on the surface of a molecular cloud and for radiatively imploding a small cloud between two hot stars have been presented in a series of papers by Sandford, Whitaker, and Klein (Sandford, Whitaker, and Klein 1982; 1984; Klein, Sandford, and Whitaker 1983), Figure 3, but they never extrapolated the idea to the formation of a globular cluster. Any leftover material in the outer shell is driven inward. The layering process repeats inward until all the matter in a large perturbation is formed into stars. The stellar abundances and masses are determined by the number and proximity of the supernovas. The distribution function of these Population II masses is the initial mass function. The masses can range over the whole spectrum but because the Population II material has higher opacity than the Population III material, and because its collapse is helped along by external forces, the masses are smaller than the Population III masses and can even be quite small. However, the smallest Population II stars are still larger than the smallest (future) Population I stars which form easily because of high opacity gas and dust. There are no initial Population II brown dwarfs.

A globular cluster can be formed at any time in any population. The only requirement is the existence of hot stars surrounding and radiatively imploding a large cloud.

Asymmetries in the distribution of the Population III stars around each large perturbation produce a small, net globular cluster velocity. Since there are excess Population III stars at the surface of galaxy-size perturbations, the globular clusters near those boundaries will be accelerated away from the boundaries and will have velocities inward on the order of a fraction of a km s^{-1}. This is the radiative trigger that leads to the gravitational implosion (violent relaxation) of the systems of globular clusters into elliptical galaxies. Figure 4 shows a schematic calculation of such violent relaxation. As galaxy-size perturbations have no symmetry, they have angular momentum and they spin up as they collapse.

At this point at z $\sim$ 10 we have a statistically uniform universe filled with elliptical galaxies. The elliptical galaxies are transparent and widely spaced, but any line of sight intersects many galaxies. For the first time the universe becomes transparent. The "microwave" background comes either from some subsequent event in galaxy-quasar evolution that produces tremendous power near 100μm, or from the pair annihilation of background neutrinos integrated from transparency until now, or from both.

All of the globular clusters in these elliptical galaxies are the same age. The globular clusters collide and gain internal energy and rapidly disintegrate. By today 99.9% of them have disintegrated. The clusters that are left are not typical or representative of the properties of the initial ensemble. They were the cold tail. They are not pure, having added and lost stars through their whole lives. The current members of one of these globular clusters are not necessarily siblings, coeval, or even Population II. There can be dark globular clusters in which all or almost all the stars are neutron stars and white dwarfs.

Both globular cluster formation and galaxy formation produce intergalactic Population II gas and stars as leftovers or as high velocity ejecta. These stars may now be main sequence dwarfs, luminous giants, white dwarfs, or neutron stars. Galaxy formation also produces intergalactic globular clusters because high velocity clusters can be ejected in the violent relaxation.

Figures 5 through 12 schematically describe galactic evolution.

If the initial mass functions of the globular clusters that form an elliptical galaxy have almost all low mass stars, the galaxy remains an elliptical galaxy forever. These galaxies have low luminosity until the giant branch is strongly populated. A few, more massive, stars lose enough mass to fill the galaxy with the tenuous gas that produces the Lyman α forest.

If the initial mass functions of the globular clusters have mostly high mass stars, the elliptical galaxy evolves into a spiral galaxy. Supernova remnants and the mass lost by intermediate mass supergiants collapse into a bulge and a disk, which spin up.

An intermediate case produces an irregular or "young" galaxy.

When there is a significant high mass tail, after some 20 million years, the whole elliptical galaxy fills with supernovas and supernova remnants. The galaxy fills with jumbled magnetic structures. The galaxy becomes opaque. The supernova remnants cannot orbit because of their large collision cross-sections. They collapse into a central bulge with a quasar at the center. The magnetic structures are swept in as well. If there is a process in all of this that produces submillimeter radiation, that radiation is the microwave background.

Since the supernova remnants have high abundances, the bulge gas has high abundances and must form high abundance stars. This can happen both in galaxies that are today elliptical or spiral. These initial quasars continue to be powered by infall of gas that is blown off intermediate mass stars when the stars climb the giant branch. This gas is low abundance Population II gas. It dilutes the supernova remnant gas. This gas forms the disk of spiral galaxies so that stars in the disk have abundances initially lower than bulge abundances. The oldest population of stars in the disk suffers many globular cluster collisions, so it is dispersed into a thick disk.

The quasars eventually run out of fuel. If later the fuel is replenished, say by galaxy-galaxy collisions, the quasar can re-ignite.

The activity that we have been describing takes place in the first 10^9 years. The time scales are set by orbital and collapse times, and by stellar evolutionary time scales. It takes, say, one orbital time to form the bulge and quasar, and a few orbital times for the mass loss infall to form the disk.

Since the disk is formed from mass-loss material from Population II stars in the halo, the mass of the disk gives a lower limit to the mass of the one- to six-solar-mass primordial Population II stars in the halo and to the number of white dwarfs. Each star loses its own mass less the mass of a white dwarf.

Since the central object and bulge are formed from Population II supernova remnants, the mass of the central object and bulge (less the equivalent volume of halo stars) give a lower limit to the mass of the, say, 7 solar mass and greater primordial Population II stars in the halo and to the number of neutron stars. Each star loses its own mass less the mass of the neutron star.

9. FORMATION OF D AND ^{3}HE

The initial Population II supernovas produce remnants with magnetic fields that accelerate cosmic rays. The halo fills with magnetic structures and cosmic rays until the supernova remnants collapse to the center to produce the quasar and bulge. The cosmic rays that are not dragged along with the magnetic fields then decay through normal collisional attrition.

The cosmic rays interact with the primordial neutrino background to undergo ladder transmutations to higher or lower elements. In particular a small fraction of ^{4}He cosmic rays are transformed into ^{3}He cosmic rays (^{4}He + $\bar{\nu}_e \rightarrow$ ^{4}H + e$^+$ = ^{3}H + n + e$^+$ $\rightarrow$ ^{3}He + n + e$^+$ + e$^-$ + $\bar{\nu}_e$, and similarly for $\bar{\nu}_\mu$ and $\bar{\nu}_\tau$) and perhaps into D (^{4}He + $\bar{\nu}_e \rightarrow$ ^{4}H + e$^+$ = ^{2}H + n + n + e$^+$, if possible). Through collisions ^{3}He cosmic rays spall into D + p. Thus D and ^{3}He are Population II artifacts and their abundances are a measure of Population II supernova activity.

Massive, relatively abundant even element cosmic rays are partially transmuted to odd element cosmic rays ((Z,A) + $\bar{\nu}_e \rightarrow$ (Z–1,A) + e$^+$; (Z,A) + $\nu_e \rightarrow$ (Z+1,A) + e$^-$).

Next we consider radiatively-driven expansion. Primordial galaxies produce a tremendous amount of radiation. Any galaxy that is a spiral now originally had most of its mass in massive stars. A 10^{12} $M_{\odot}$ spiral galaxy produces, say, 10^{11} supernovas yielding 10^{62} ergs. The precurser stars radiate even more during their lifetimes, say 10^{63} ergs. There might be $3\text{x}10^{11}$ intermediate mass stars that radiate 10^{63} ergs and end up as white dwarfs. In addition the quasar itself produces 10^{46}- 10^{47} ergs s^{-1} for say $3\text{x}10^{8}$ years or about 10^{63} ergs. There is also a great deal of energy from the collapse that heats the gas and is eventually radiated away, partly by the quasar. If half the large galaxies are spirals, it is easy to produce 10^{51} ergs $M_{\odot}{}^{-1}$ averaged over all galaxies. [Neutrinos produced by the supernovas add up to a similar amount of energy.]

During the first billion years galaxies are much closer together than now. If that era corresponds to redshifts of say z=10 to z=5, galaxies are between 11 and 6 times closer than now. Statistically it is possible for a large group of galaxies (say 10^{5}) to be optically thick to their own radiation (except for radio). Any photon emitted at the center passes through so many spiral galaxies that it must be absorbed, Figure 13. Thus the clump of galaxies expands from its own radiation pressure. Galaxies with high projected opacity-to-mass ratios, perhaps face-on spirals, are accelerated the most, followed by all the other spirals. The elliptical galaxies are dragged along by gravitational attraction. A low density region forms and continues to expand from radiation pressure as long as the galaxies are very bright and until the clump of galaxies becomes optically thin. The expansion of the universe eventually guarantees the latter. Eventually the role of radiation becomes insignificant compared to gravity.

Regős and Geller (1991) have shown that some of the small, low-density expanding regions in a uniform background will continue to expand gravitationally as the universe expands, Figure 14. They form voids that collide and merge. The collisions produce galaxy clusters, streaming in the void walls, and eventually the large scale structure that we see today.

11. SUMMARY

A Big Bang universe consisting, before recombination, of a gas of H, D, ^{3}He, ^{4}He, ^{6}Li, and ^{7}Li ions, electrons, photons, and massless neutrinos at a density sufficient to produce a flat universe, will evolve into the universe as we now observe it. Evolution during the first billion years is controlled by radiation.

The universe has evolved as follows since recombination:

1) There were pre-existing galaxy-size perturbations.

2) Recombination halved the gas pressure and removed the outward radiative acceleration from these perturbations thereby producing an inward impulse. The impulse generated waves that interfered and shocked to fill the large perturbations with globular-cluster-size perturbations.

3) The smallest perturbations formed superluminous Population III stars whose radiation caused

4) larger perturbations to implode and form globular clusters of Population II stars, and then

5) systems of globular clusters suffered radiatively-triggered collapse (violent relaxation) into elliptical galaxies, some of which

6) evolved to form quasars and spirals that

7) gave off so much radiation that, in some places, statistically, voids were formed by radiation pressure, and then

8) void collisions and void walls produced clusters of galaxies and the large scale flows and structure that we see today.

9) The microwave background radiation is recent, younger than the galaxies.

The number of Population III stars was very small and they all exploded so that only remnants are left. Essentially all matter has been processed in stars. The interstellar medium was produced by stars. The intergalactic medium was produced by galaxies. It is not primordial.

All spiral and irregular galaxies that have not been damaged by collisions or interactions have large, massive, elliptical halos.

Figure 15 is the table of contents for our galaxy. Our galaxy has a halo containing about 10^{11} neutron stars, $3\text{x}10^{11}$ white dwarfs, visible K and M stars, and 10^{11} slightly evolved low mass stars (all numbers to astronomical accuracy). It also has over 10^2 coeval globular clusters that are the remnants of 10^6 primordial globular clusters from which our galaxy was formed. There is a central, inactive, quasar surrounded by a bulge of high abundance Population II stars. Both were made from the first Population II supernova remnants which collapsed from the halo to the center of the galaxy. The disk was made from gas lost by intermediate mass Population II stars in the halo when they evolved up the giant branch, and that gas subsequently collapsed into the disk and spun up to conserve angular momentum. Thus the disk has lower abundances than the bulge, even though it was formed later. There were still many globular clusters at the time of disk formation so many disk stars were scattered by collisions with globular clusters and formed a thick disk population. There are stars in the halo and globular clusters that were formed in the disk or bulge and were accreted by globular clusters and carried into the halo. The stars in globular clusters need not be siblings, coeval, or Population II. Non-primordial globular clusters could have been formed in the bulge, the disk, or in collapsing gas clouds.

During the first billion years evolution was controlled by changing matter into radiation in massive stars. Gravity became dominant only after these initial bursts of radiation were exhausted.

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FIGURE CAPTIONS

Figure 1. Big Bang abundances work if the density is chosen to close the universe.

Figure 2. Schematic globular-cluster-size perturbations superposed on top of galaxy-size perturbations.

Figure 3. Simulations of radiatively-driven implosions of Population I clouds indicate the plausiblity of forming a globular cluster by surrounding a cloud with hot stars.

Figure 4 qualitatively demonstrates that small radiative accelerations are sufficient to trigger the collapse of a universe full of globular clusters into a universe full of elliptical galaxies. I borrowed the program from Regős that she used to model void formation (Regős and Geller 1991). The universe is periodically tesselated into cubes with constant density of globular clusters, 128**3 per cube. Each cube is subdivided into 8 parallellopipeds as shown in the upper left. This is an arbitrary choice intended not to look like galaxy precursers. All the surfaces of all the parallellopipeds are given a small inward velocity as would be produced by excess supernovas at the the surfaces. The initial condition is zero gravitational force. The small motion of the surface globular clusters is enough to cause violent relaxation into a galaxy, except in one case where neighboring galaxies cause the smallest object to disintegrate and then assimilate its remains.

Figure 5. Schematic evolution of galaxy of 1/2 $M_\odot$ stars.

Figure 6. Schematic evolution of galaxy of 1 $M_\odot$ stars.

Figure 7. Schematic evolution of galaxy of 10 $M_\odot$ stars.

Figure 8. Schematic evolution of galaxy with distribution function peaking at 2/3 $M_\odot$ stars.

Figure 9. Schematic evolution of galaxy with distribution function peaking at 1 $M_\odot$ stars.

Figure 10. Schematic evolution of galaxy with distribution function peaking at 10 $M_\odot$ stars.

Figure 11. Evolution of our galaxy.

Figure 12. Isolated galaxy classification as a function of galaxy mass and of stellar mass distribution function peak.

Figure 13. The galaxies are so close together that for some large samples any ray out from the center intersects enough spiral galaxies to be absorbed. The collection of galaxies is optically thick.

Figure 14. Regős and Geller (1991) showed that starting with a uniform density universe, one could evolve voids and large scale structure by removing half the matter from small spheres and redistributing it in expanding shells.

Figure 15. Table of contents of our galaxy.

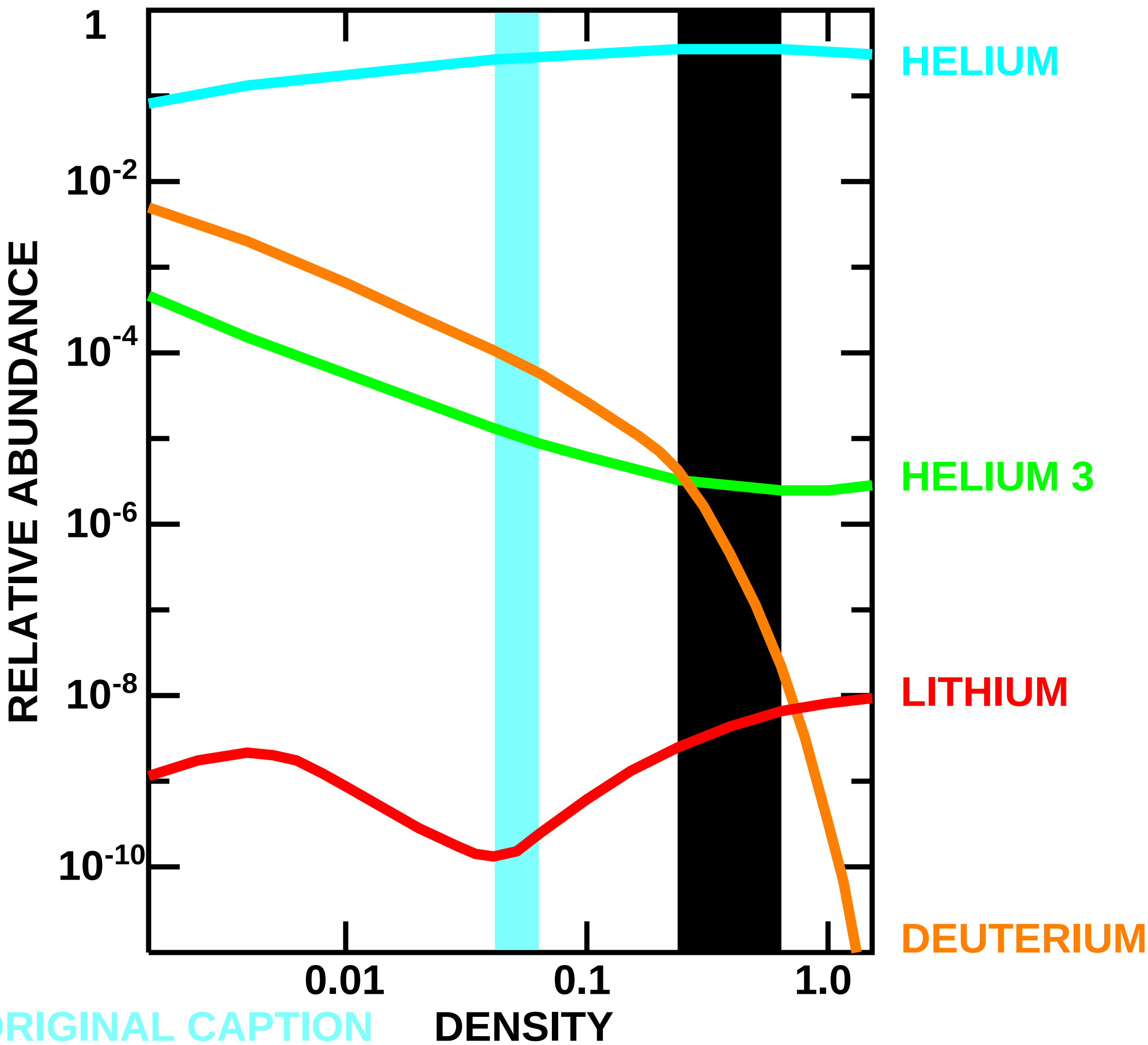
FIG 1

PRIMORDIAL ABUNDANCES

FIGURE BASED ON PEEBLES, SCHRAMM, TURNER, AND KRON IN SCIENTIFIC AMERICAN, OCTOBER 1994, PP. 52-57.

LIGHT BLUE REGION ENCOMPASSES INCORRECT OBSERVED ABUNDANCES THAT IMPLY A LOW DENSITY UNIVERSE.

BLACK REGION ENCOMPASSES THE TRUE ABUNDANCES THAT IMPLY A DENSITY SUFFICIENT TO CLOSE THE UNIVERSE AND THAT DARK MATTER IS BARYONIC.



ORIGINAL CAPTION

DENSITY of neutrons and protons in the universe determined the abundances of certain elements. For a higher density universe the computed helium abundance is little different, and the computed abundance of deuterium is considerably lower. The shaded region is consistent with the observations, ranging from an abundance of 24 percent for helium to one part in 10^{10} for the lithium isotope. The quantitative agreement is a prime success of the big bang cosmology.

FIG 2

SCHEMATIC PERTURBATION SPECTRA

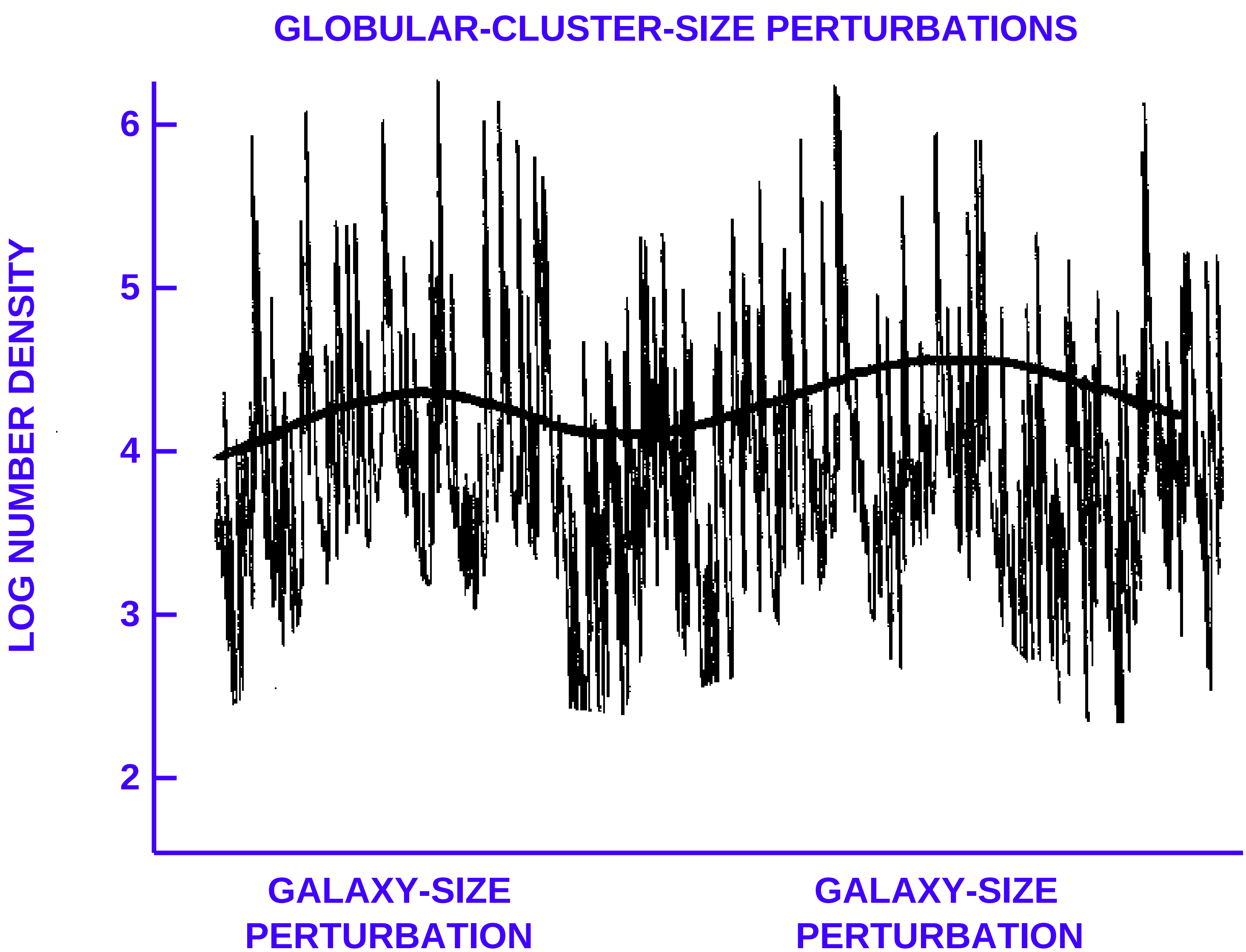
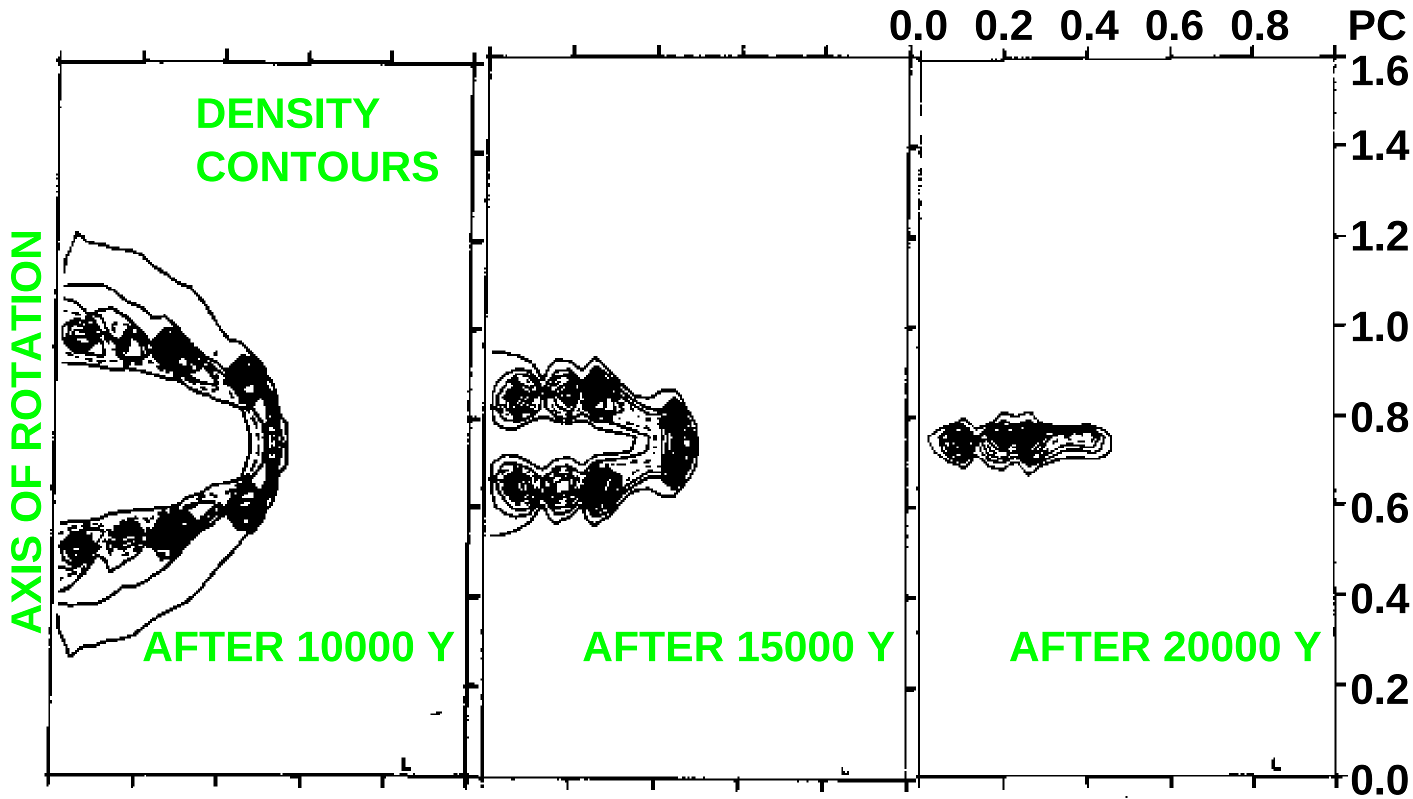


FIG 3

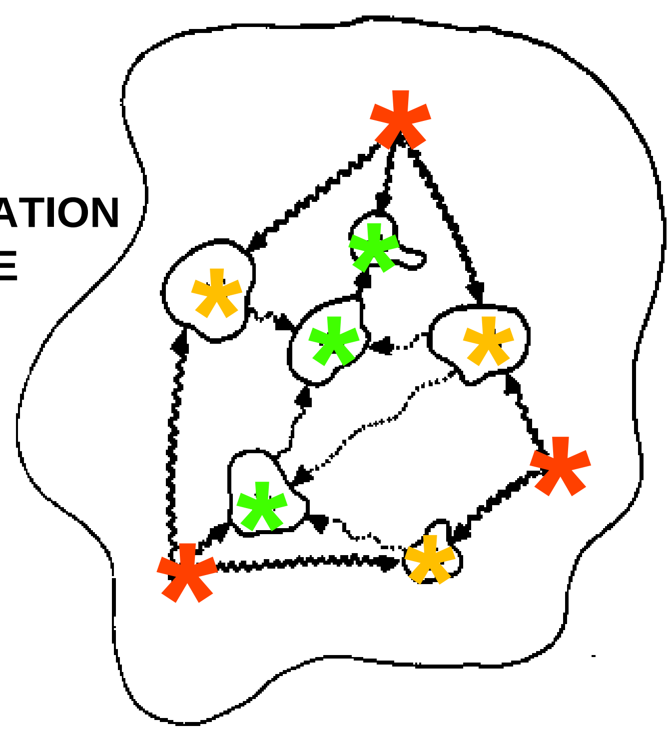
STAR FORMATION BY RADIATIVELY-DRIVEN IMPLOSION

KLEIN, SANDFORD, AND WHITAKER 1983
SANDFORD, WHITAKER, AND KLEIN 1982; 1984

IMPLOSION OF A CLOUD BETWEEN TWO O STARS



OPEN CLUSTER FORMATION THROUGH SUCCESSIVE GENERATIONS OF IMPLOSIONS



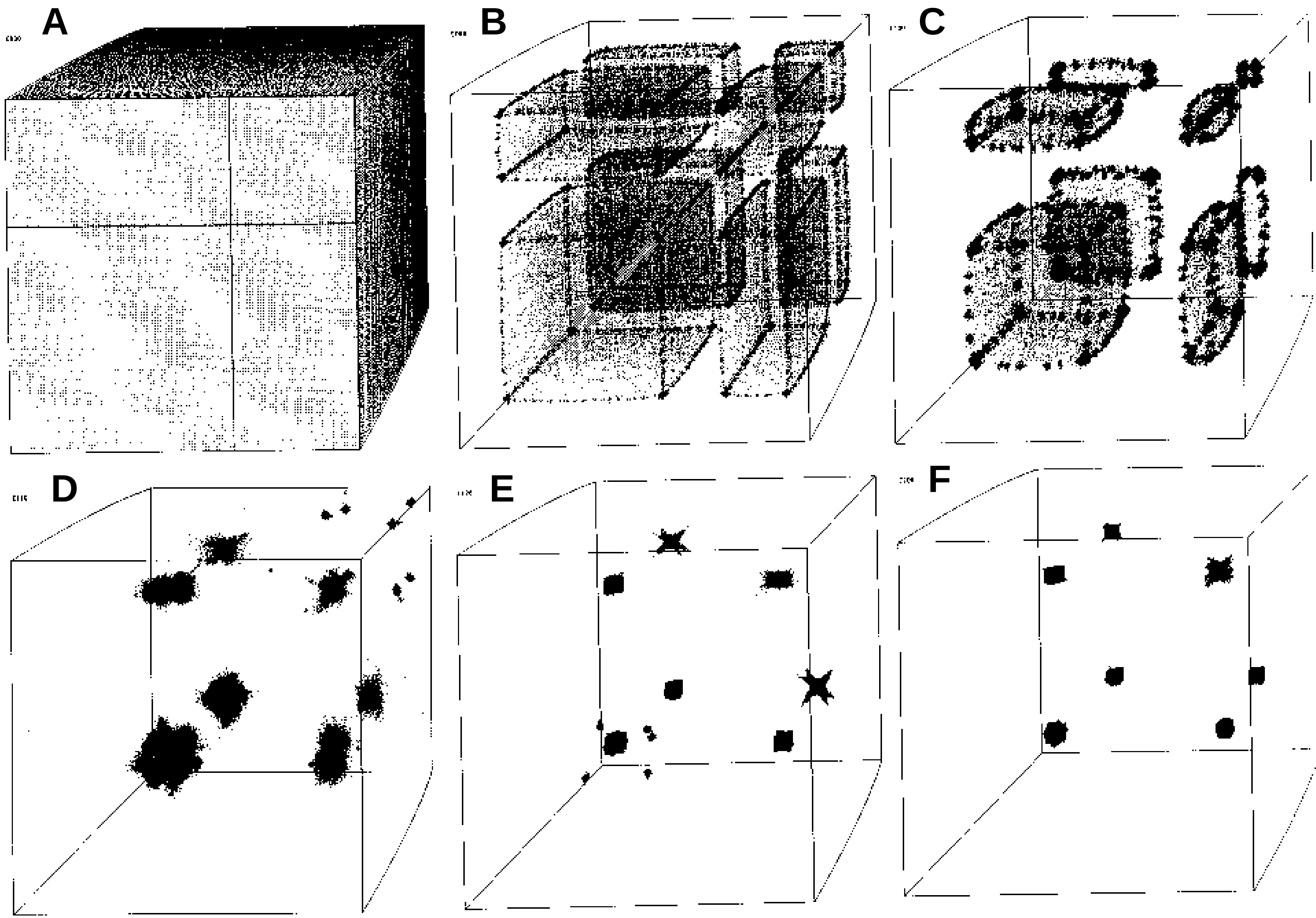
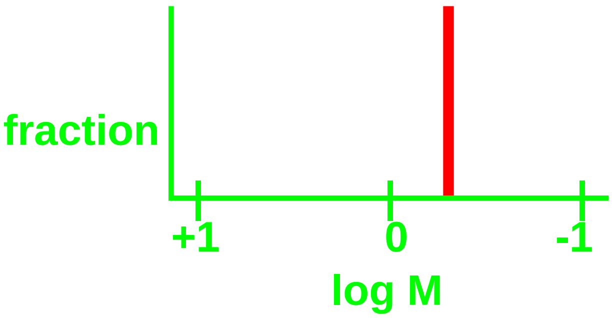


FIG 4

FIG 5

SCHEMATIC DISTRIBUTION FUNCTIONS FOR ISOLATED ELLIPTICAL GALAXIES



δ-function 1/2 $M_\odot$

total 10^{12} $M_\odot$

THEN

2×10^{12} STARS WITH 1/10 $L_\odot$

IN ELLIPTICAL GALAXY TOO FAINT TO SEE

TRANSPARENT, CAN SEE OTHER GALAXIES THROUGH IT

NOW AFTER ~15 GY

2×10^{12} STARS WITH ~ $L_\odot$

IN FAINT ELLIPTICAL GALAXY

TRANSPARENT BUT

SMALL AMOUNT OF GAS FROM MASS LOSS

PRODUCES ABSORPTION LINES IN SPECTRA

SEEN THROUGH IT

EDITORIAL

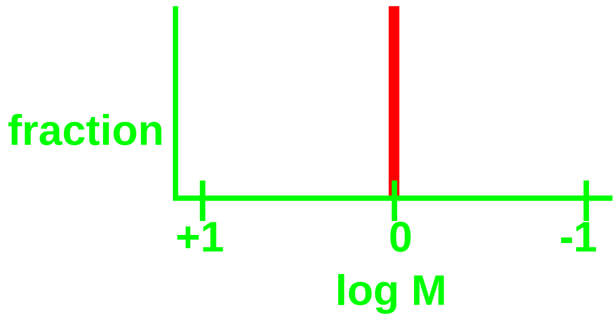
ALWAYS CONSIDER THE EVOLUTIONARY PERSPECTIVE

WHAT WAS IT LIKE IN THE PAST?

WHAT WILL IT BE LIKE IN THE FUTURE?

DO NOT BE BLINDED BY VISUAL APPEARANCE NOW

FIG 6



δ-function 1 $M_\odot$

THEN

10^{12} STARS WITH $L_\odot$
IN ELLIPTICAL GALAXY TOO FAINT TO SEE
HALO TRANSPARENT

5 GY AGO

GALAXY 500 TIMES BRIGHTER FOR, SAY, 1/10 GY
STARS LOSE 1/2 MASS > WHITE DWARFS
HALO OPAQUE WITH 5 x 10^{11} $M_\odot$
POP II GAS + 10^{12} WHITE DWARFS

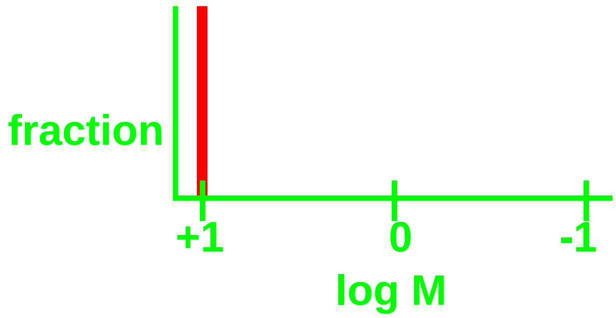
5-4 GY AGO

CLOUDS HAVE LARGE COLLISION CROSS-SECTIONS
IF IN HALO COALESCE AS IRREGULAR
IF AT CENTER OR DISK COALESCE AS SPIRAL
GAS + DUST FORM NEW STARS
ABUNDANCES HIGHER THAN ORIGINAL BUT STILL LOW
SOME NEW STARS ARE HIGH MASS
GALAXY BECOMES VERY BRIGHT

NOW

STILL VERY BRIGHT
LOW ABUNDANCE IRREGULAR OR SPIRAL
LOTS OF OPAQUE GAS + DUST
HALO NOT OBVIOUS

FIG 7



δ-function 10 $M_\odot$

THEN

10^{11} STARS WITH 10^{4} $L_\odot$

VERY BRIGHT ELLIPTICAL GALAXY

TRANSPARENT

AFTER 0.01 - 0.1 GY

FEW SUPERNOVAS/DAY FOR FEW MY

ALL STARS SUPERNOVA

OPAQUE FROM MASS LOSS + SUPERNOVA REMNANTS

HALO FILLED WITH 10^{11} NEUTRON STARS

10^{11} SN REMNANTS COLLAPSE INTO DISK AND BULGE

REMNANTS CANNOT PASS THROUGH BULGE OR DISK

COLLAPSE IS ~ 1/2 ORBITAL PERIOD ~ 1/10 GY

CORE SPINS UP AND IS HEATED BY INFALL

BECOMES SUPERQUASAR THAT JETS OUT THE POLES

REMNANTS ARE HIGH METAL ABUNDANCE

BULGE + DISK FORM HIGH ABUNDANCE STARS

AFTER 1 GY

GALAXY IS DUSTY SPIRAL

WORN OUT QUASAR AT CENTER

HALO WITH 10^{11} DEAD STARS

NOW

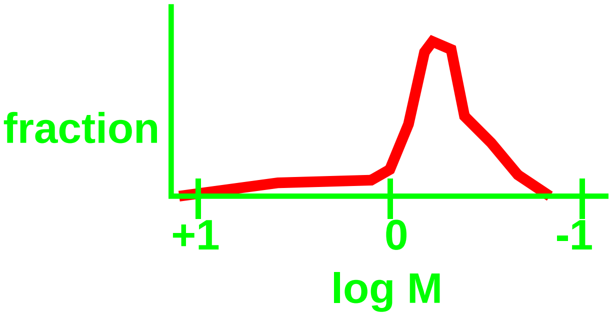
LOOKS THE SAME

ENRICHED BY MANY GENERATIONS OF SUPERNOVAS

POP 0 STARS

FIG 8

MORE REALISTIC DISTRIBUTION FUNCTIONS FOR ISOLATED ELLIPTICAL GALAXIES



peak 2/3 $M_\odot$

THEN

$\sim 2 \times 10^{12}$ STARS IN ELLIPTICAL GALAXY

~1% BRIGHT,   SOME SUPERNOVA

IF HIGH MASS TAIL IS LARGE ENOUGH REMNANTS COLLECT AT CENTER AND PRODUCE QUASAR

NOW

LOOKS LIKE NORMAL ELLIPTICAL GALAXY

$\sim 10^{10}$ NEUTRON STARS

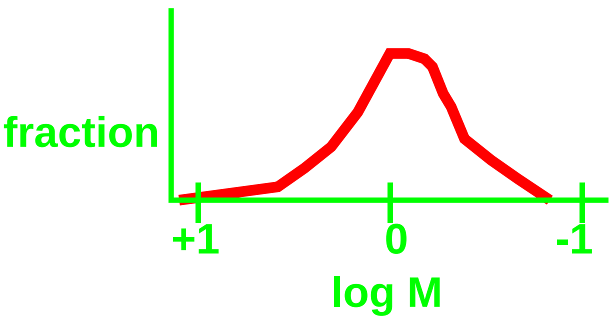
$1\text{-}3 \times 10^{11}$ WHITE DWARFS

MANY FAINT LOW MASS STARS

FUTURE

WILL STILL LOOK LIKE NORMAL ELLIPTICAL GALAXY

FIG 9



peak 1 $M_{\odot}$

THEN

$\sim 10^{12}$ STARS IN ELLIPTICAL GALAXY
GALAXY IS ALWAYS BRIGHT
ALWAYS HAS SUPERNOVAS AND SN REMNANTS
REMNANTS COLLECT AT CENTER
ACTIVE CORE OR QUASAR DEPENDING ON MASS

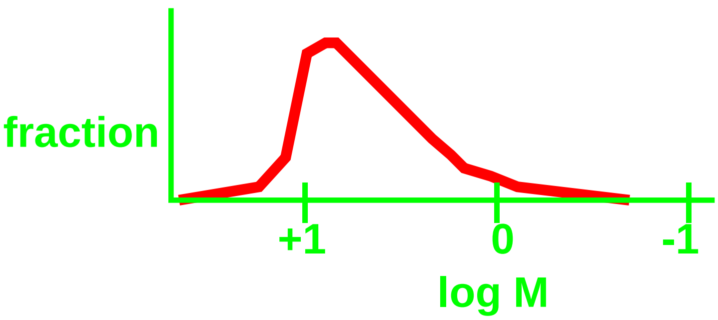
5 GY AGO

VERY BRIGHT WITH MANY BRIGHT SUPERGIANTS
TREMENDOUS AMOUNT OF GAS AND DUST
IF GAS COLLAPSES, A SPIRAL FORMS
HAS A QUASAR OR VERY ACTIVE CORE
IF NO ORGANIZED COLLAPSE
IRREGULAR GALAXY FORMS

NOW

MASSIVE HALO
10^{12} UNEVOLVED, K GIANT, AND DEAD STARS
LOTS OF STAR FORMATION
VERY BRIGHT
ABUNDANCES STILL LOW

FIG 10

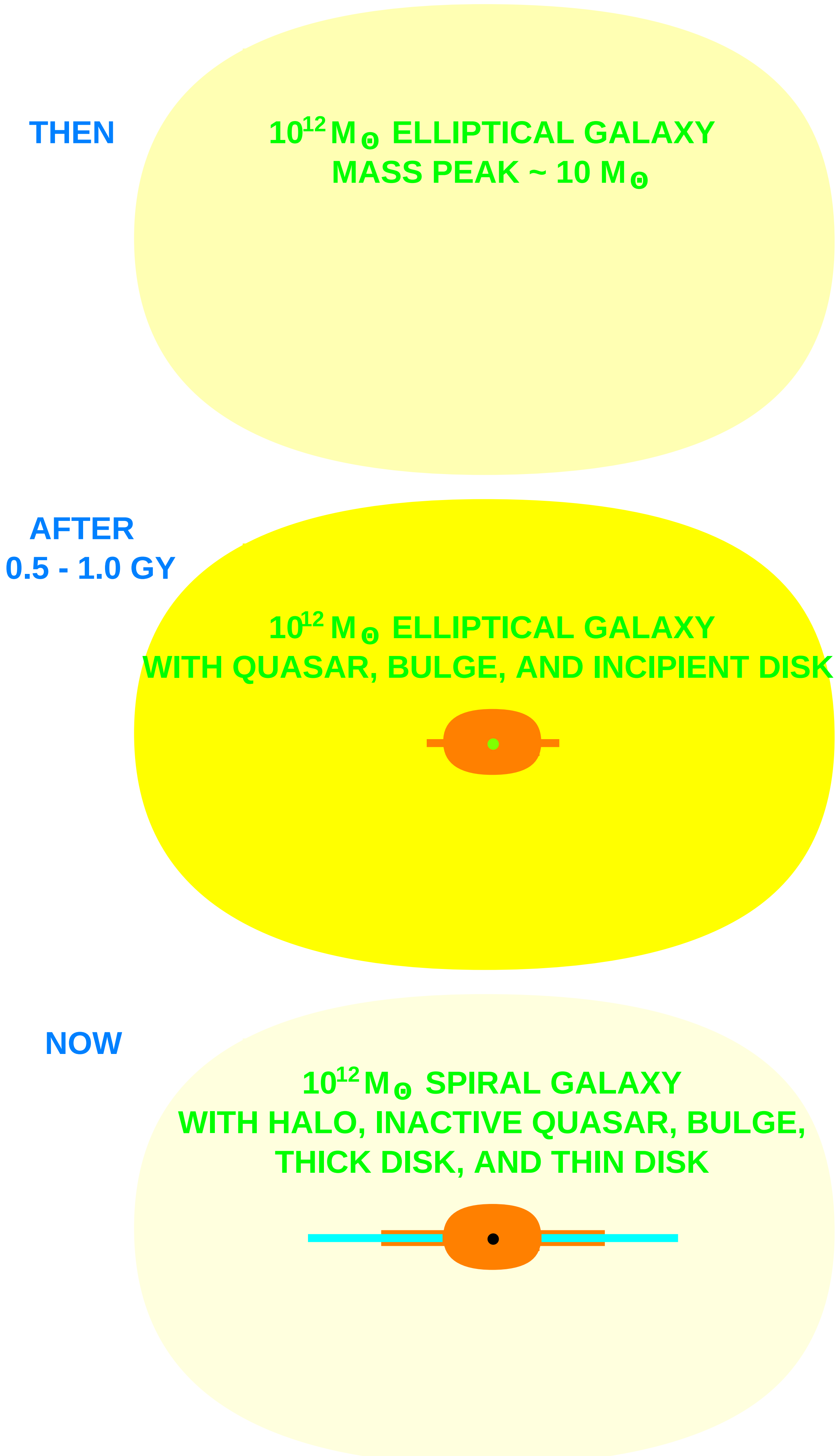


peak 10 $M_\odot$

THEN

LIKE 10 $M_\odot$ δ-function, FIG 7, BUT MODERATED
ONLY ~ 10^{10} SUPERNOVAS, A FEW PER MONTH

FIG 11



THEN
$10^{12} M_{\odot}$ ELLIPTICAL GALAXY
MASS PEAK ~ 10 $M_{\odot}$
AFTER
0.5 - 1.0 GY
$10^{12} M_{\odot}$ ELLIPTICAL GALAXY
WITH QUASAR, BULGE, AND INCIPIENT DISK
NOW
$10^{12} M_{\odot}$ SPIRAL GALAXY
WITH HALO, INACTIVE QUASAR, BULGE,
THICK DISK, AND THIN DISK

FIG 12

CLASSIFICATION OF GALAXIES
ISOLATED WITH NO STRIPPING AND NO MERGERS

HUBBLE CLASSIFICATION IS SUPERFICIAL MORPHOLOGY
ALL GALAXIES ARE PRIMORDIAL AND ELLIPTICAL
PHYSICAL VARIABLES

- MASS
- DISTRIBUTION FUNCTION OF THE MASSES (IMF)
  - OF THE ORIGINAL POP II STARS
  - PEAK MASS, HIGH-MASS TAIL, LOW-MASS TAIL
- ANGULAR MOMENTUM, ETC

ELLIPTICALS
ANON MANY FAINT, TRANSPARENT WITH VERY LOW-MASS PEAK

M32 LOW MASS, LOW-MASS PEAK, FAINT UNTIL RECENTLY.

M87 HIGH MASS, LOW-MASS PEAK, ENOUGH HIGH-MASS TAIL TO PRODUCE QUASAR

IRREGULARS
SMC SMALL MASS, MEDIUM-MASS PEAK. MUCH POP II MASS LOSS SEVERAL GY AGO. CONTINUAL STARBURST SINCE.

LMC MEDIUM MASS, MEDIUM-MASS PEAK. MUCH POP II MASS LOSS SEVERAL GY AGO. CONTINUAL STARBURST SINCE. HIGH-MASS TAIL WAS STRONGER THAN LMC'S SO HIGHER ABUNDANCES IN NEW STARS

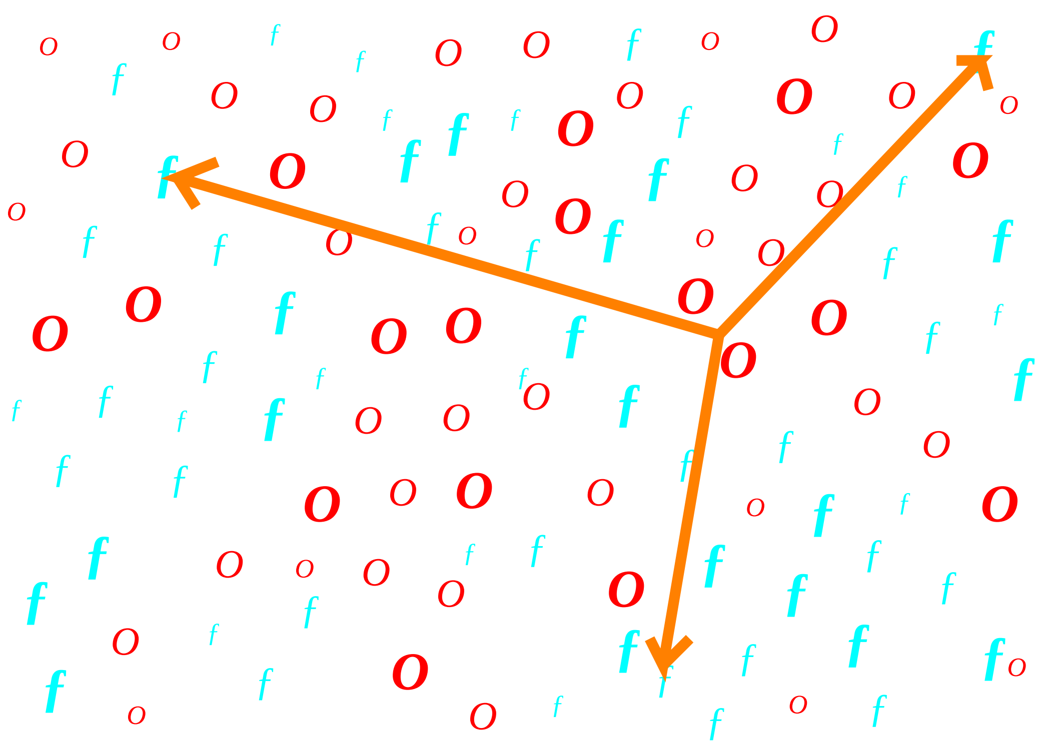
SPIRALS
M33 LOW MASS, HIGH-MASS PEAK. EVOLVES AS IN FIG 11.
M31 HIGH MASS, HIGH-MASS PEAK. EVOLVES AS IN FIG 11.
MW HIGH MASS, HIGH-MASS PEAK. EVOLVES AS IN FIG 11.

MAKING VOIDS WITH RADIATION PRESSURE

THERE ARE ~10^{12} GALAXIES WITHIN OUR HORIZON

UNTIL Z ~ 5 GALAXIES WERE SO MUCH CLOSER THAN NOW THAT, STATISTICALLY, A CLUMP OF, SAY, 10^5 GALAXIES COULD BE OPTICALLY THICK

ALL RADIATION FROM NEAR THE CENTER IS ABSORBED (EXCEPT RADIO)

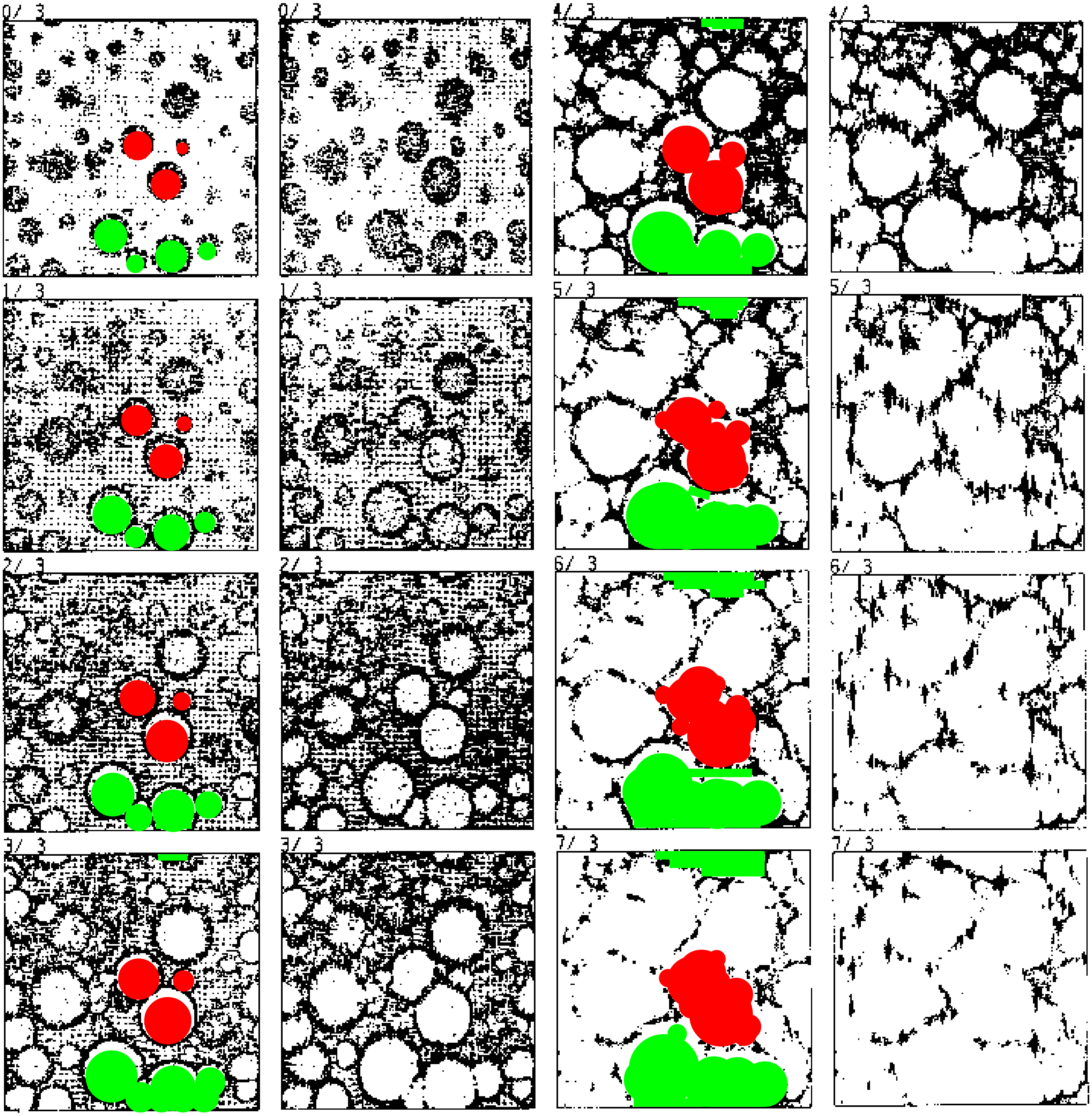


OPAQUE GALAXIES ABSORB THE RADIATION AND ARE ACCELERATED OUTWARD

THEY DRAG ALONG THE ELLIPTICALS GRAVITATIONALLY

FIG 14

EVOLUTION OF VOIDS AND LARGE SCALE STRUCTURE



REGŐS AND GELLER (1991) MODELLED COSMOLOGICAL EVOLUTION OF VOIDS UP TO THE PRESENT TIME. THESE ARE 5% 2D SLICES THROUGH THE 3D PERIODIC CUBIC STRUCTURE. DENSE AREAS IN THE FINAL PANELS ARE CLUSTERS OF GALAXIES.

FIG 15

CONTENTS OF OUR GALAXY

HALO

$\sim 10^{7}$ POP III NEUTRON STARS OR BLACK HOLES
FROM SUPERMASSIVE POP III STARS

$\sim 10^{11}$ POP II NEUTRON STARS
FROM MASSIVE POP II STARS

$\sim 3 \times 10^{11}$ WHITE DWARFS
FROM INTERMEDIATE MASS POP II STARS

$\sim 10^{11}$ K + M STARS
INITIAL POP II

$\sim 10^{2}$ GLOBULAR CLUSTERS
INITIAL POP II

BULGE

1 INACTIVE QUASAR AT CENTER

$\sim 10^{11}$ HIGH ABUNDANCE POP II K + M STARS

$\sim 10^{1}$ GLOBULAR CLUSTERS
ALL FROM POP II SUPERNOVA REMNANT INFALL

$\sim 10^{10}$ WHITE DWARFS
FROM EVOLVED BULGE STARS

THICK DISK

$\sim 10^{9}$ BULGE STARS
ESCAPED OR PULLED OUTWARD INTO DISK

$\sim 10^{9}$ INTERMEDIATE POP I-II STARS
FROM MIXED HALO AND BULGE MASS LOSS

THIN DISK

$\sim 10^{9}$ OLD STARS WITH ABUNDANCES LOWER THAN BULGE
FROM POP II MASS LOSS THAT COLLAPSES INTO DISK

$\sim 10^{11}$ POP I STARS OF INCREASINGLY HIGHER ABUNDANCE
FROM POP I GAS AND DUST LOCALLY PRODUCED

$\sim 10^{11}$ $M_{\odot}$ GAS AND DUST
FROM POP I MASS LOSS AND SUPERNOVAS

$\sim 10^{10}$ WHITE DWARFS AND NEUTRON STARS
FROM EVOLVED POP I STARS